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THE ATMOSPHERES OF THE MOON, PLANETS AND SUN.

BY G. H. BRYAN, M. A., CAMBRIDGE, ENGLAND.

IT was only a week or two before reading Professor Liveing's interesting communication in *Science* that I had made some calculations which led me to adopt the same theory which he has advocated. The object of my investigations was, in fact, to show that we could not regard the atmospheres of the different members of the solar system as isolated masses of gas, from which molecules might fly off if their speeds were to become sufficiently great, but that, to account for the very existence of planetary atmospheres at all, it would be necessary to adopt the hypothesis of an atmosphere of excessive tenuity pervading both interplanetary and interstellar space.

It is unfortunate that Mr. Howard did not apply the principle of conservation of energy to the arguments contained in his letter in the issue of April 28. Had he done so he would have realized that the question as to whether a molecule will permanently leave the atmosphere of the Moon or a planet depends only on its speed, irrespective of direction, and does not in any way depend on whether the motion takes place in a vertical direction. In fact, if the kinetic energy of a molecule is greater than the work required to be done against the planet's attraction in order to remove the molecule to an infinite distance, the molecule will describe a hyperbola, and will fly off never to return again, no matter what be its direction of motion, provided that it does not come into collision with any other molecule or with the planet itself.

Again, the speed required to leave the Earth is about five times as great as that required to leave the Moon; but this is not because the earth's attraction is five times as great as the Moon's, but because the Earth's *potential* is about twenty-five times as great as the Moon's, consequently, in order to leave the Earth, a particle would require to have twenty-five times the kinetic energy, or five times the speed, which it would require to leave the Moon.

According to the well-known "error law" of distribution of speed among the molecules of a gas, which forms the basis of calculations connected with the kinetic theory, there must always be *some* molecules moving with sufficiently great speeds to overcome the attraction of any body, however powerful, and *some* whose speed is too small to enable them to escape from the attraction of any body, however feeb e. On this assumption no planet can have an absolutely permanent atmosphere, and no planet or satellite which has ever had an atmosphere could get rid of that atmosphere entirely. If, however, the proportion of molecules which escape is relatively exceedingly small, any changes which occur in the nature of the atmosphere of the planet will take place so slowly that countless ages will have to elapse before they make themselves felt. In order, therefore, to test the relative degree of permanence of the atmospheres of different celestial bodies, I have calculated what proportion of the molecules of oxygen and hydrogen at different temperatures have a sufficiently great speed to fly off from the surfaces of, and never return to, the Moon, Mars and the Earth. I have also given the corresponding results for the Sun, not, however, at its surface, but at the Earth's distance from the Sun's centre, where the critical speed is, of course, square root of two times the speed of the Earth's orbital motion.

The numbers, which are given in Table 1 below, represent in each case the average number of molecules, among which there is *one* molecule whose speed exceeds the critical amount. Thus, for oxygen at temperature 0°C, rather over one molecule in every *three billion* is moving fast enough to fly off permanently from the Moon, and only one in every $2.3\text{x}10^{329}$ is moving fast enough to escape from the Earth's atmosphere, while the Sun's attraction, even at the distance of the Earth, prevents more than one in every $2\text{x}10^{4940}$ from escaping.

When we arrive at such vast numbers as this, it might be reasonable to object that we have pushed the kinetic theory a great deal further than it will go. The assumptions made in many proofs of the "error" law of distribution certainly preclude its application to high speeds that are so rarely attained. Still there is no physical limit to the speed which any individual molecule might acquire in the course of colliding with other molecules. As Professor Liveing has pointed out, all that would be necessary would be a sufficiently long run of collisions, in each of which the line of impact happened to be nearly perpendicular to the direction in which the molecule in question was previously moving, so that each impinging molecule should transfer the greater portion of its energy to that one molecule.

And theory points to the conclusion that whenever there is any law of permanent distribution of the molecules of a gas, that law must be the "error" law. Hence the calculations may be reasonably expected to give a correct estimate of the proportion of molecules whose speed exceeds the critical speed, provided that the mass of gas under consideration is so large that the *total* number of such molecules is great, however small their relative proportion may be. Thus we are at least justified in regarding the figures as affording indications of the relative permanency or otherwise of the gaseous envelopes surrounding different bodies of the solar system.

One great difficulty presented by the theory is that oe taking account of the differences of temperature of the atmospheres of the different bodies. There seems to be good reason for believing that the Moon's temperaturf may fall below —200°C., in which case only one molecule in $7\text{x}10^{51}$ will be able to escape. And generally the larger members of the solar system are the hotter, and this would cause them to part with their atmospheres more readily in proportion than they would if all the bodies were at one common temperature. If the absolute temperatures of different bodies were proportional to their gravitation potentials, the proportion of molecules possessing the speed requisite to carry them off would be the same for all. This condition would require the Earth's atmosphere to have an absolute temperature roughly twenty-five times as high as that of the Moon's. Even supposing this were the case, it does not necessarily